



WBS 3.1 - Trigger

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CMS Trigger Project Manager

DOE/NSF Review
May 19, 1998

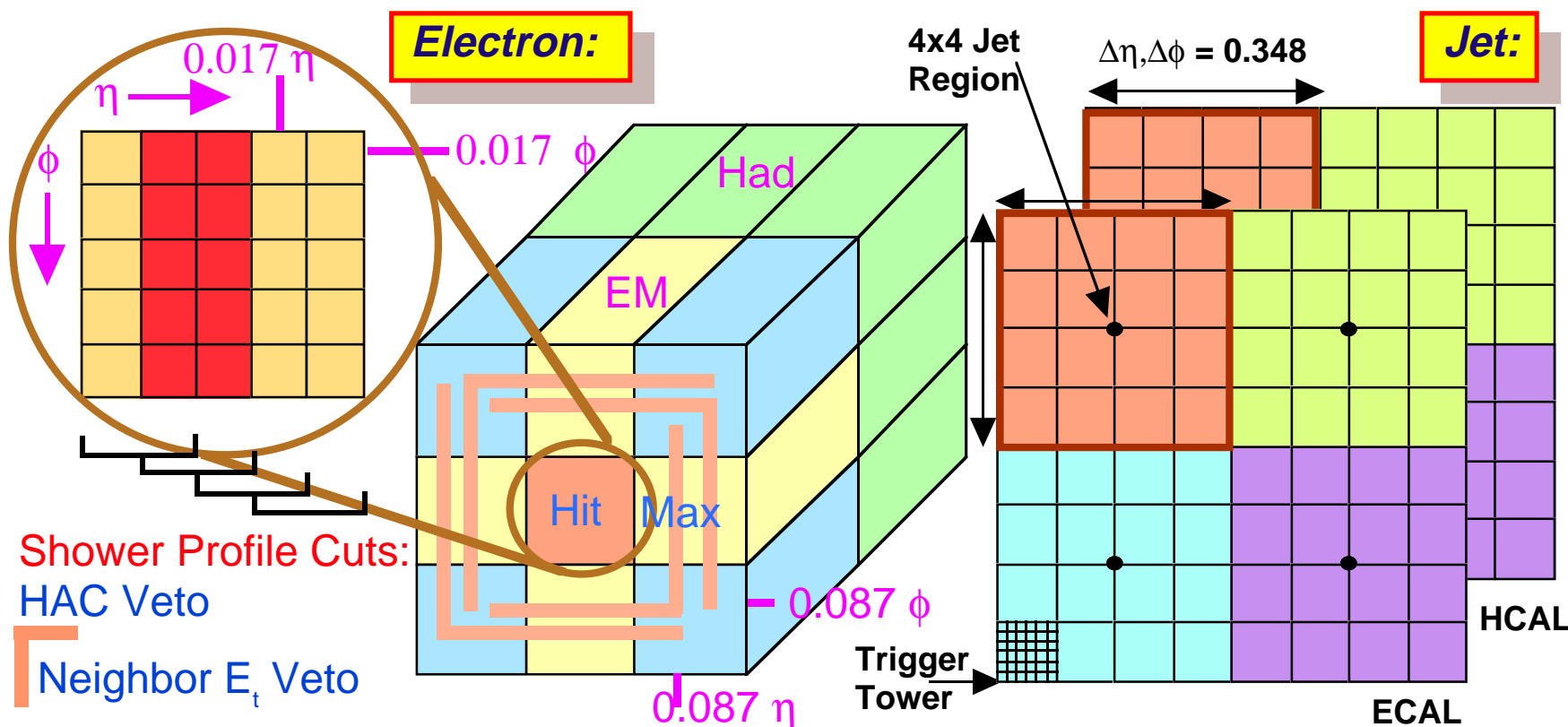


Outline

- **Overview of Calorimeter Trigger**
- **Overview of Muon Trigger**
- **Organization**
- **Cost Estimate**
- **Scope and Contingency Since Last Review**
- **WBS, Milestones, and Schedule**
- **Commitment and Resource Profiles**
- **Status & Progress**
- **Committee Concerns and Corrective Actions**
- **Summary and Conclusions**



Calorimeter Triggers



**3 x 3 sliding window
centered on ECAL/HCAL
trigger tower pairs**
Tower count =
 $72\phi \times 54\eta \times 2 = 7776$

**Jet E_t from sum of ECAL & HCAL
trigger tower E_t in non-overlapping 4x4
regions (also used for $E_x, E_y, E_t, E_t^{Miss}$)**
Use multijet triggers
**Jet candidates are sorted to find
highest energy jets**



Calorimeter Trigger Overview

4K 1 Gb/s serial links with:
 2 x (8 bits EM or HAC Energy)
 + 5 bits error detection code
 (+ fine grain isolation (or H1) bit)
 72 ϕ x 54 η Towers (.087x.087ea.)
 every 25 ns.

US CMS HCAL:
FNAL/
Maryland

Calorimeter
Electronics
Interface

CMS ECAL:
Lisbon/
Palaiseau

Copper40 MHz Parallel
 4 Highest E_t e/γ
 4 Highest jets
 E_x, E_y from each crate

US CMS Trigger:
U. Wisconsin

Calorimeter
Regional
Trigger
(WBS 3.1.2)
Receiver
Electron Isolation
Jet/Summary

E_t sums

US CMS HCAL:
U. Nebraska

Lumi-
nosity
Monitor

US CMS HCAL:
U. Nebraska

Lumi-
nosity
Monitor

E_t sums

Cal. Global Trigger
Sorting, E_t^{Miss} , ΣE_t

UK CMS:
Bristol

CMS:
Vienna

Global
Trigger
Processor

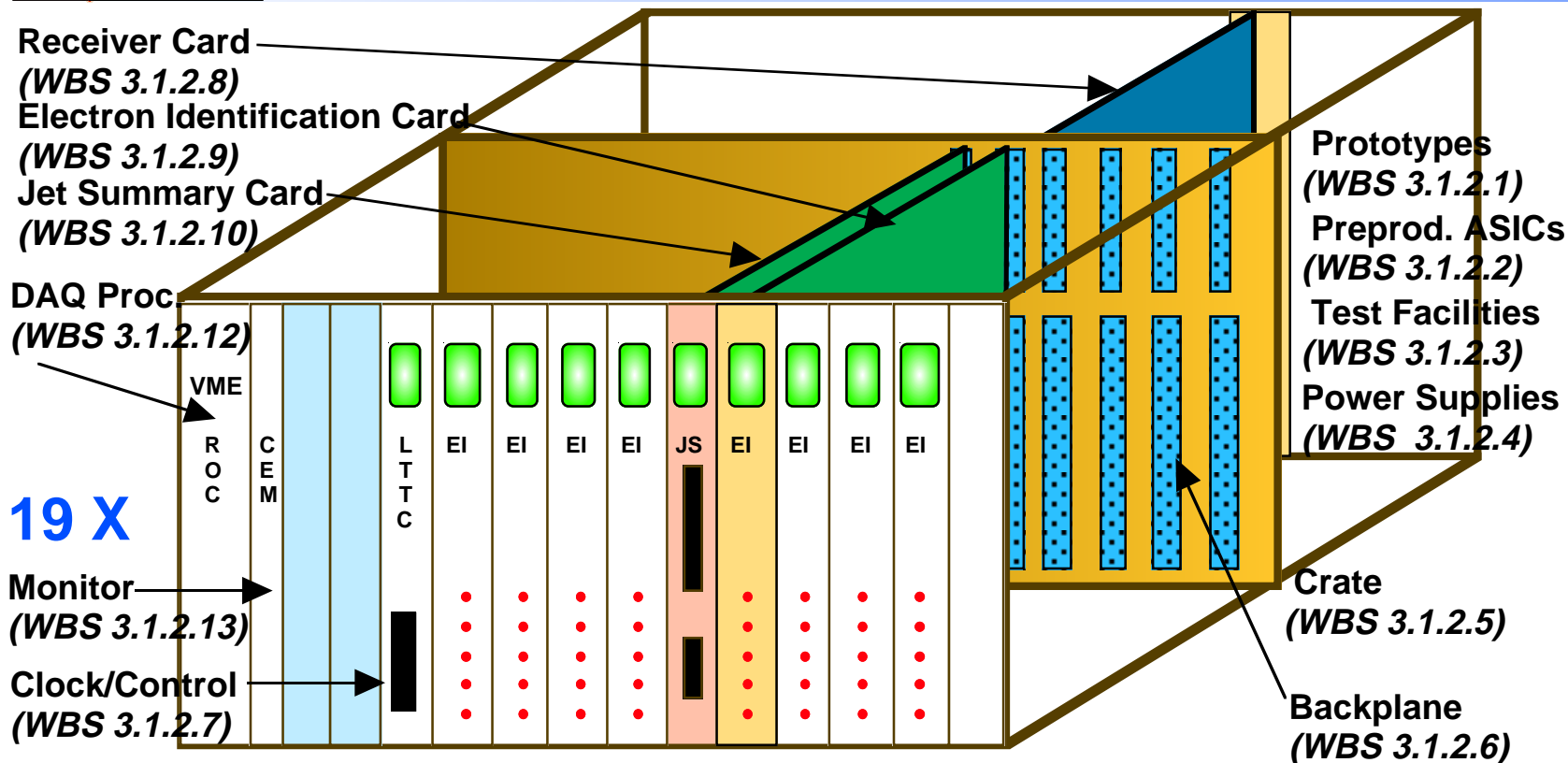
Muon Global Trigger
Iso Mu Minlon Tag

Minlon Tag for
each $4\phi \times 4\eta$ region



Regional Calorimeter Crate

(WBS 3.1.2)



Data from calorimeter FE on Cu links @ 1.2 Gbaud

- Into 152 rear-mounted Receiver Cards (proto. being built)

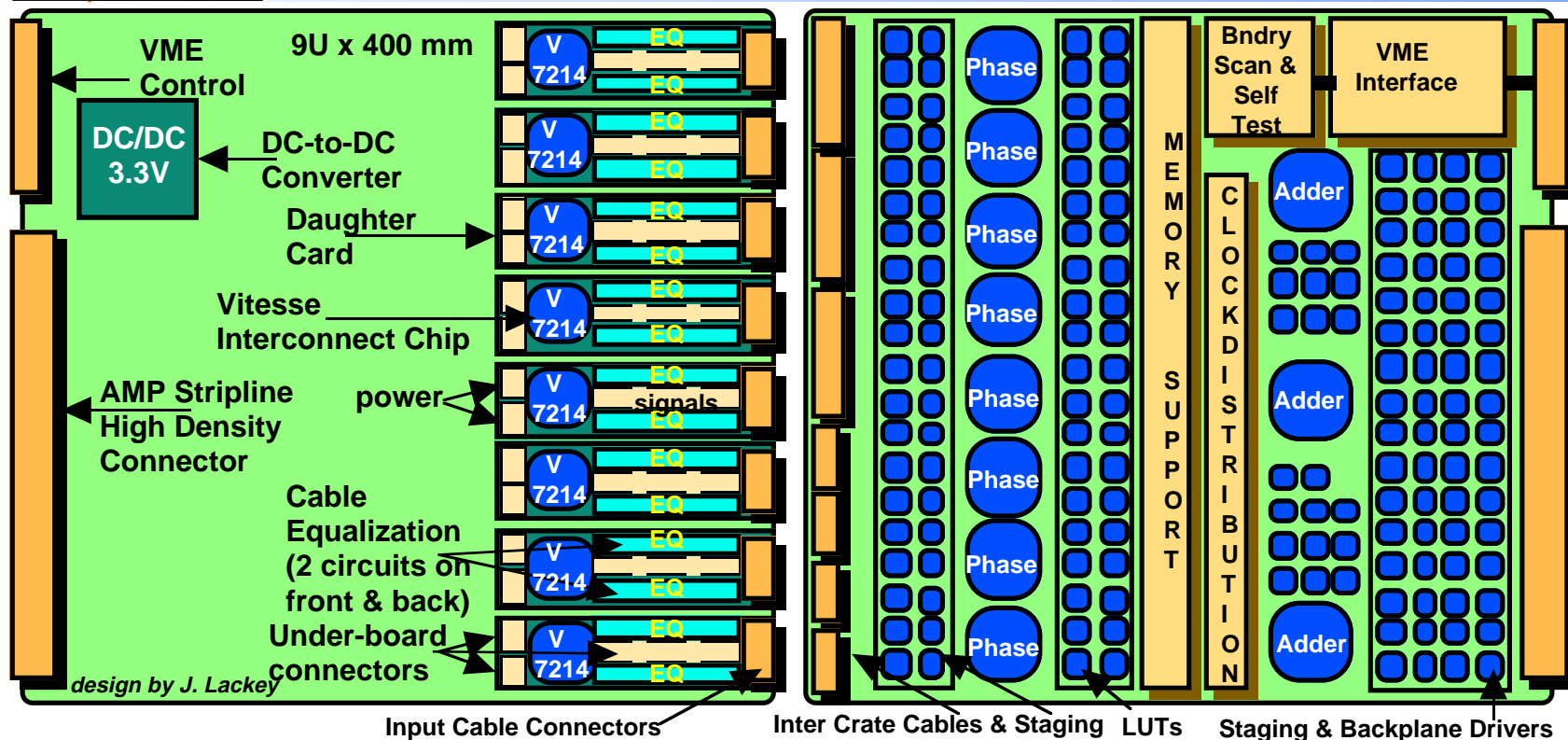
160 MHz point to point backplane (proto. built)

- 19 Clock&Control (proto. built), 152 Electron Identification, 19 Jet/Summary, Receiver Cards operate @ 160 MHz



3.1.2.8: Receiver Card

(prototype being built by U. Wisconsin)



Rear:

32 Channels =

4 Ch. x 8 daughter cards

1.2 GBaud copper rcvrs

18 bit (2x9) data + 5 bit error

Vitesse Chip:

Converts Serial to Parallel

Front: Data from Rear @ 120 MHz TTL

Phase ASIC: Deskew, Mux @ 160MHz

Error bit for each 4x4, Test Vectors

Memory LUT @ 160 MHz

Adder ASIC:

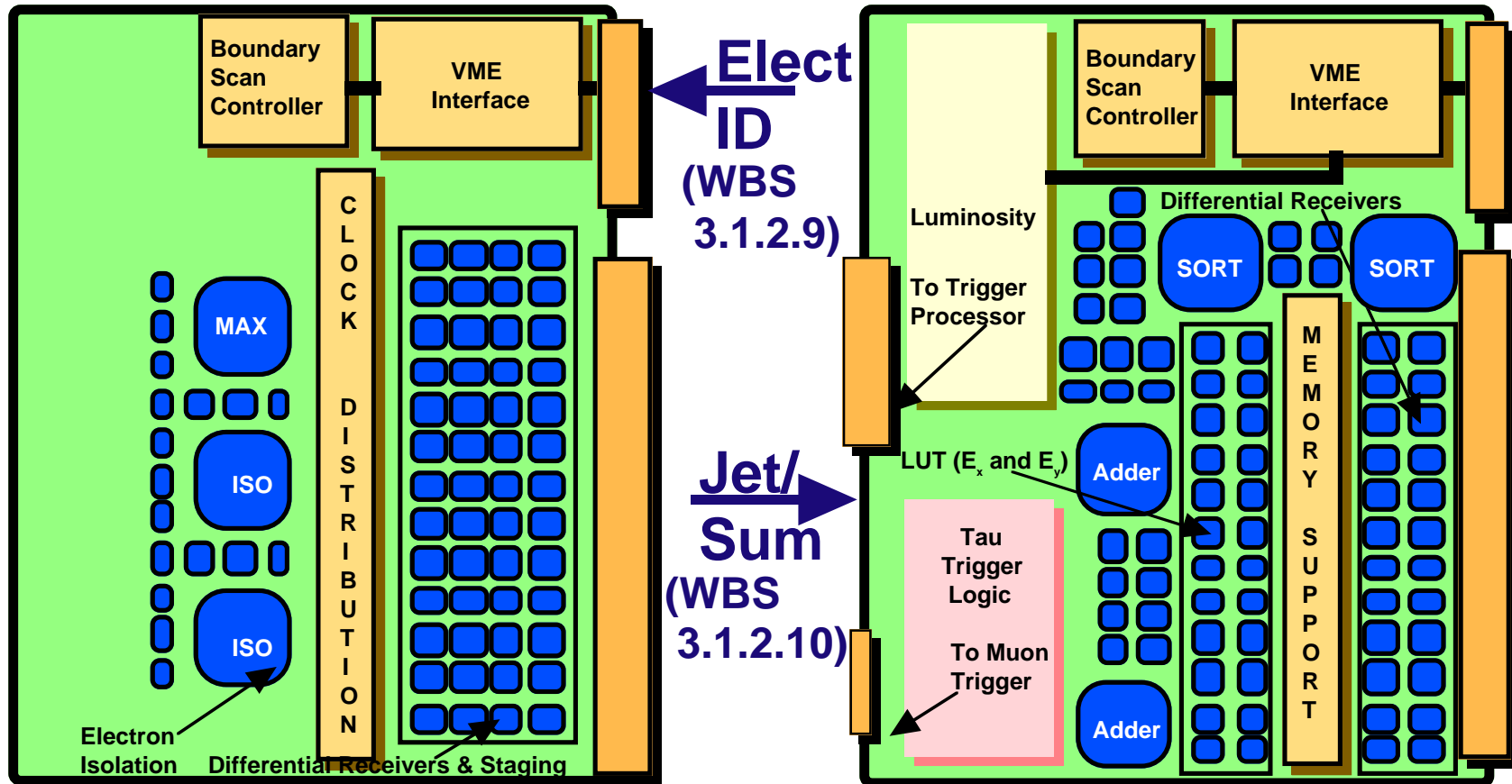
8 inputs @ 160 MHz in 25 ns. (built!)

Differential Output @ 160 MHz



Electron ID & Jet/Summary Cards

(U. Wisconsin)



Processes 4x8 region @ 160 MHz
Electron isolation on ASIC
Lookup tables for ranking
Takes Max in each 4x4

Summarizes full crate:
Sorts 32 e's, 4x4 E_t → top 4 e's, jets
LUTs: E_x & E_y from E_t for 4x4 area
Adder tree for E_t, E_x and E_y sums
Quiet/Minl bits for each 4x4 region



Physics at low luminosity

(Luminosity = $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$)

Trigger Type	Trigger Et Cutoff (GeV)	Rate (kHz)				Process	Efficiency (%)		
		CMSIM		FASTSIM			CMS-TN-95/183	FASTSIM	CMSIM
		Individual	Incremental	Individual	Incremental				
						$p\,p \rightarrow t\,t \rightarrow e\,X$	99	97	97
Sum Et	150	1.0	1.0	1.2	1.2	$p\,p \rightarrow t\,t \rightarrow H^+ X \rightarrow t\,X$	99	94	94
Missing Et	40	2.7	1.7	3.1	2.0	$p\,p \rightarrow b\,b$ (hadronize), $B \rightarrow e\,X$	0.2 (But 400Hz)	-	-
Electron	12	11.4	9.1	5.4	4.4	SUSY CMS TP Scenario A	98	-	-
DiElectron	7	1.2	1.9	0.4	1.0	($M_{LSP} = 45$, $M_{\text{spart}} \sim 300$ GeV)			
Single jet	50	1.5	0.3	1.8	0.6	SUSY Neutral Higgs	45 - 98	30 - 96	39 - 96
Dijet	30	1.3	0.3	1.7	0.4	(Range of $\tan b$ and M_H values)			
Trijet	20	0.8	0.1	1.1	0.1	<div>Signal efficiency</div> <div>High efficiency is realized for the benchmark processes involving top decays and SUSY sparticles</div>			
Quad jet	15	0.6	0.04	0.8	0.1				
Jet+Elctrn	15 & 9	11.2	3.4	5.6	2.0				
Cumulative Rate		17.8		11.8					

Signal efficiency

High efficiency is realized for the benchmark processes involving top decays and SUSY sparticles.

QCD Background

CMSIM and FASTSIM rates are compared for the low luminosity E_t cutoffs.

Electron trigger rate is twice as high in CMSIM results

Notes:

A dedicated tau trigger is under study to improve efficiency for the low mass range of SUSY Higgs.

There is also high rate of B signal in level-1 sample.



Physics at high luminosity

$$\text{Luminosity} = 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$$

Trigger Type	Trigger Et Cutoff (GeV)	Rate (kHz)				Process	Efficiency (%)		
		CMSIM		FASTSIM			CMS-TN-95/183	FASTSIM	CMSIM
		Individual	Incremental	Individual	Incremental				
Sum Et	400	0.3	0.3	0.4	0.4	H (80 GeV) $\rightarrow \gamma \gamma$	97	92	94
Missing Et	80	1.2	0.9	1.7	1.3	H (120 GeV) $\rightarrow Z Z \rightarrow e e \mu \mu$	76*	76*	74*
Electron	25	11.4	9.3	4.5	3.9	H (200 GeV) $\rightarrow Z Z \rightarrow e e j j$	99	96	95
DiElectron	12	2.1	1.8	1.0	1.0	p p $\rightarrow t t \rightarrow e X$	88	82	82
Single jet	100	1.5	1.0	2.0	1.3	p p $\rightarrow t t \rightarrow H + X \rightarrow t X$	82	76	76
Dijet	60	1.2	0.7	1.9	1.1	SUSY CMS TP Scenario A (M _{LSP} = 45, M _{spart} ~ 300 GeV)	83#	-	-
Trijet	30	2.3	1.3	3.1	1.8	Signal Efficiency High efficiency for all channels with			
Quadjet	20	2.6	1.1	3.3	1.4				
Jet+Elctrn	50 & 12	1.3	0.3	0.7	0.2				
Cumulative Rate		16.7		12.4					

Signal Efficiency

High efficiency for all channels with electrons and photons.

The difficult-to-trigger top decay events have high efficiency, enabling studies of associated Higgs production.

*Inclusion of muon trigger gives full efficiency

QCD Background

The sum & missing E_t cutoffs chosen to yield 2 kHz rate.

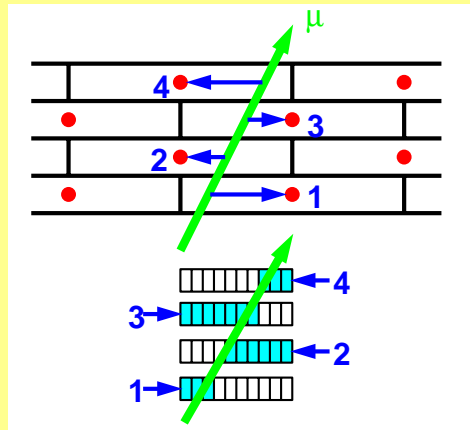
Electron/photon triggers are emphasized, ~8 kHz rate out of total available 15 kHz.

Remaining 5 kHz available for jet triggers.

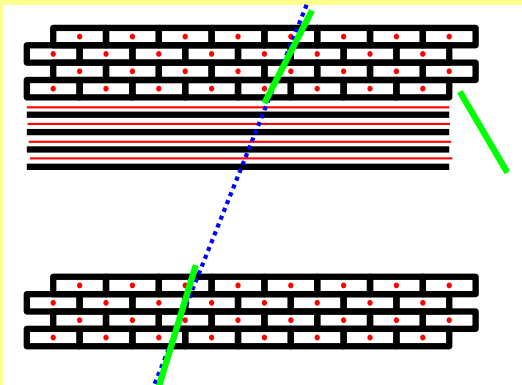


Muon Chamber Trigger

Drift Tubes

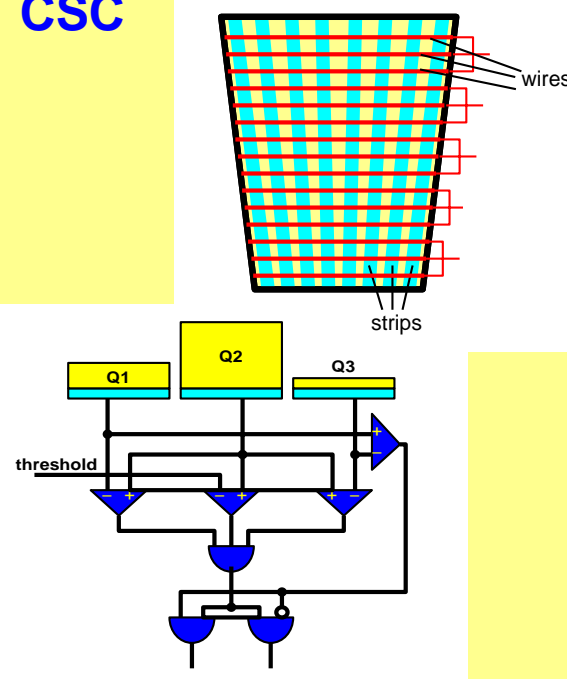


Meantimers recognize tracks and form vector / quartet.

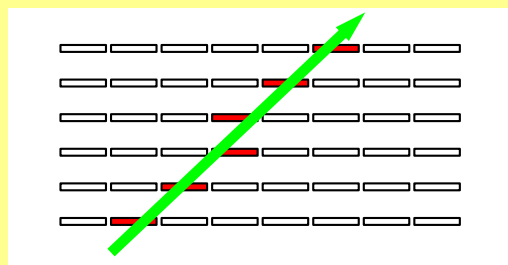


Correlator combines them into one vector / station.

CSC

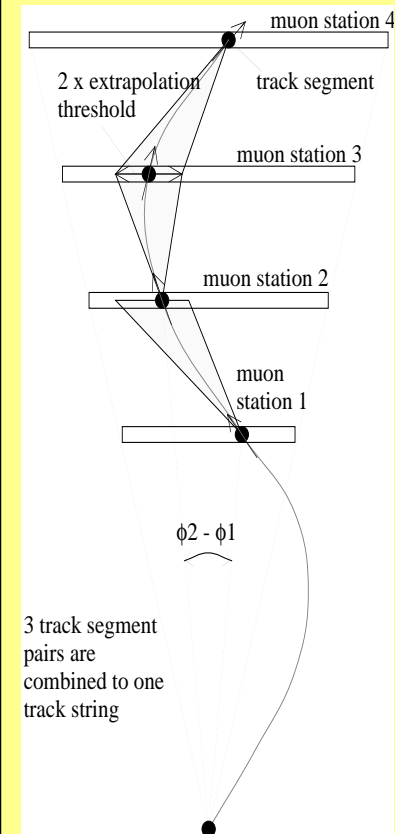


Comparators give 1/2-strip resol.



Hit strips of 6 layers form a vector.

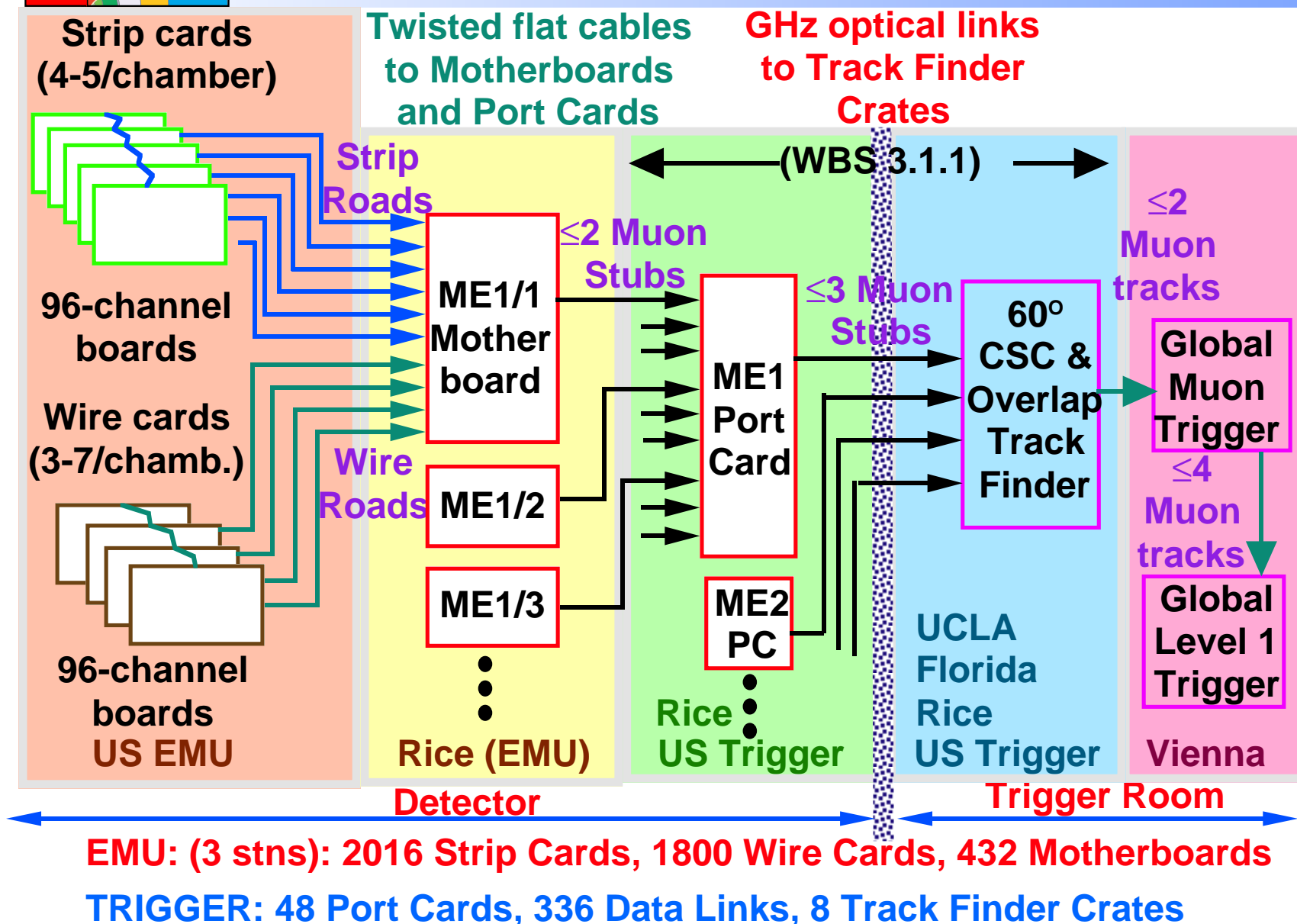
Track Finder



- combines vectors,
- forms a track,
- assigns p_t value.



CSC Trigger Layout



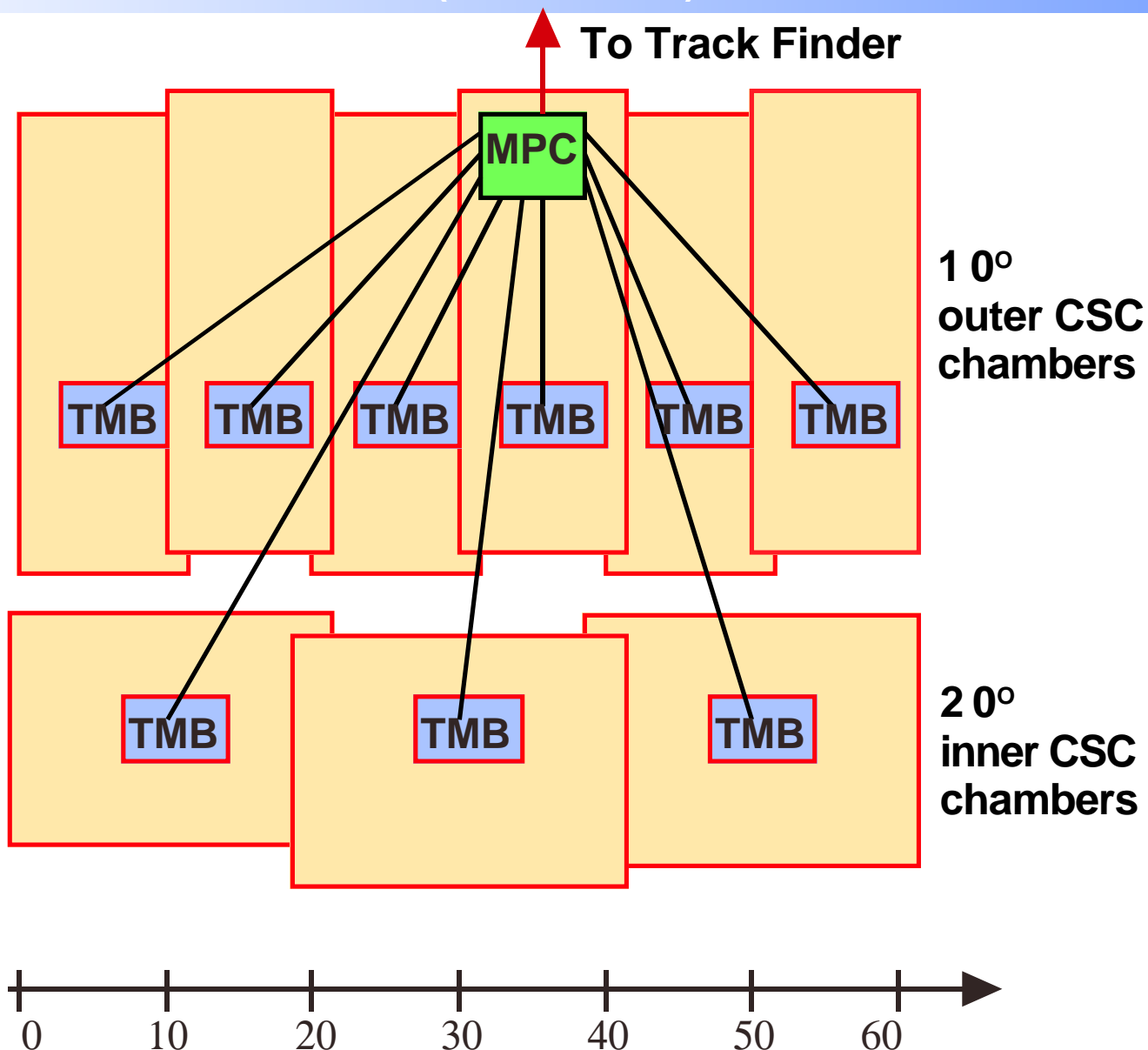


CSC Trigger Port Cards

(WBS 3.1.1.1)

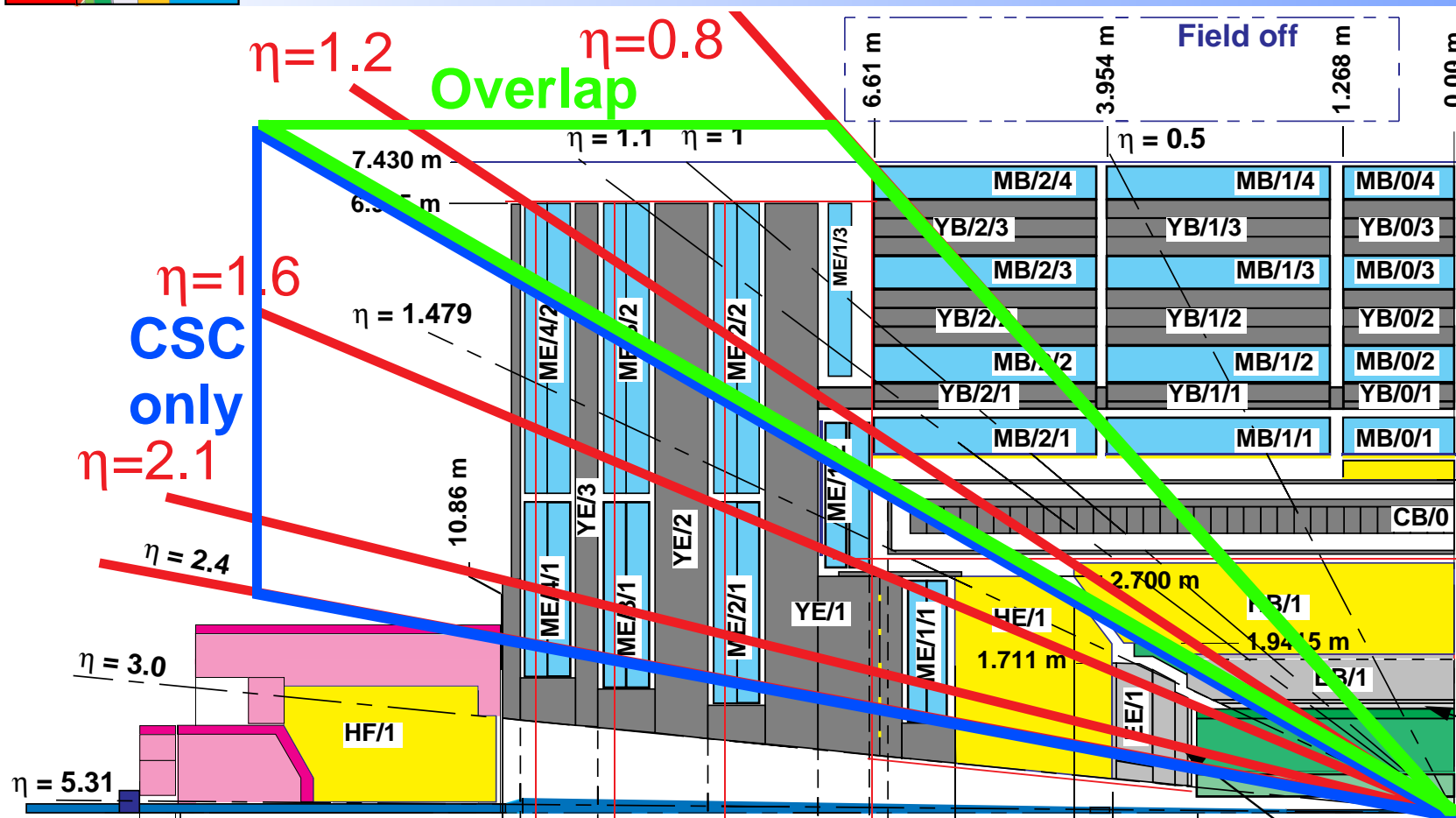
TMB =
Trigger
MotherBoard

MPC =
Muon
Port Card





CSC Muon Trigger Geometry



CSC Track-finding:

- Two Types of Crates:
 - 4 Overlap Crates
 - 4 CSC-only Crates

Two Sector Processors

SP-Overlap: CSC's & Barrel DT's

SP-CSC: CSC's only

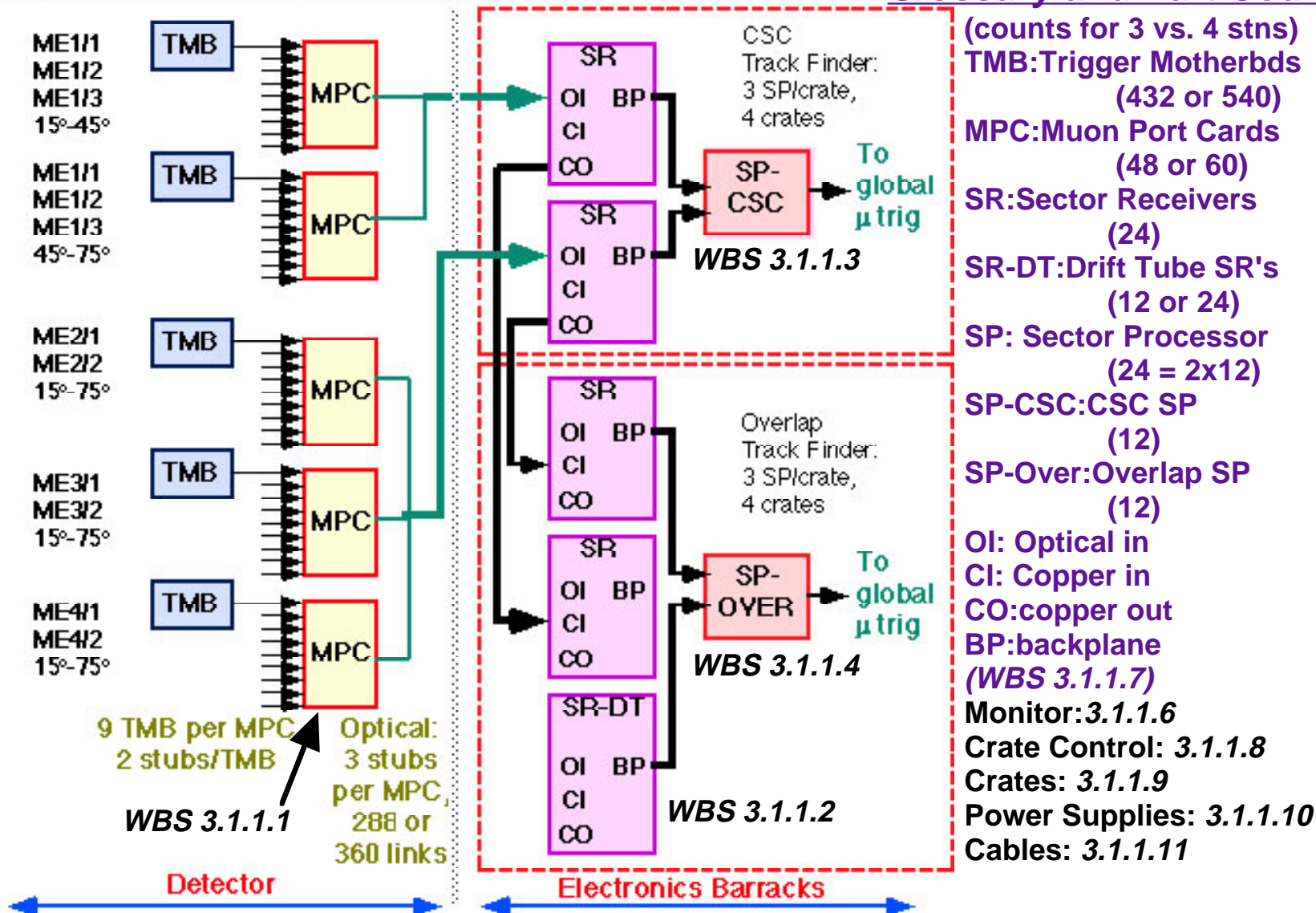
One Receiver Card: DT & CSC



CSC & Overlap TF Block Diagram

Diagram of the first 60° Sector (15-75 degrees)

Glossary and Part Count





Muon & Cal Trigger Rates

Low & High Luminosity:

	$L = 10^{33} \text{cm}^{-2} \text{s}^{-1}$			$L = 10^{34} \text{cm}^{-2} \text{s}^{-1}$		
trigger type	threshold [GeV]	rate [kHz]	cumulative rate [kHz]	threshold [GeV]	rate [kHz]	cumulative rate [kHz]
μ	7	9.8	9.5	20	7.8	7.8
$\mu \mu$	2-4	0.5	10.1	4	1.6	9.2
$\mu e/\gamma$	2-4, 6	2.5	12.2	4, 8	5.5	14.4
μe_b	2-4, 5	3.5	13.4	—	—	—
μj	2-4, 12	2.2	14.5	4, 40	0.3	14.4
μE_t^{miss}	2-4, 40	0.8	14.7	4, 60	1.0	15.3
$\mu \Sigma E_t$	2-4, 150	0.8	14.7	4, 250	0.2	15.3

threshold = 2-4 GeV means: 4 GeV in the barrel, 2 GeV in the endcaps

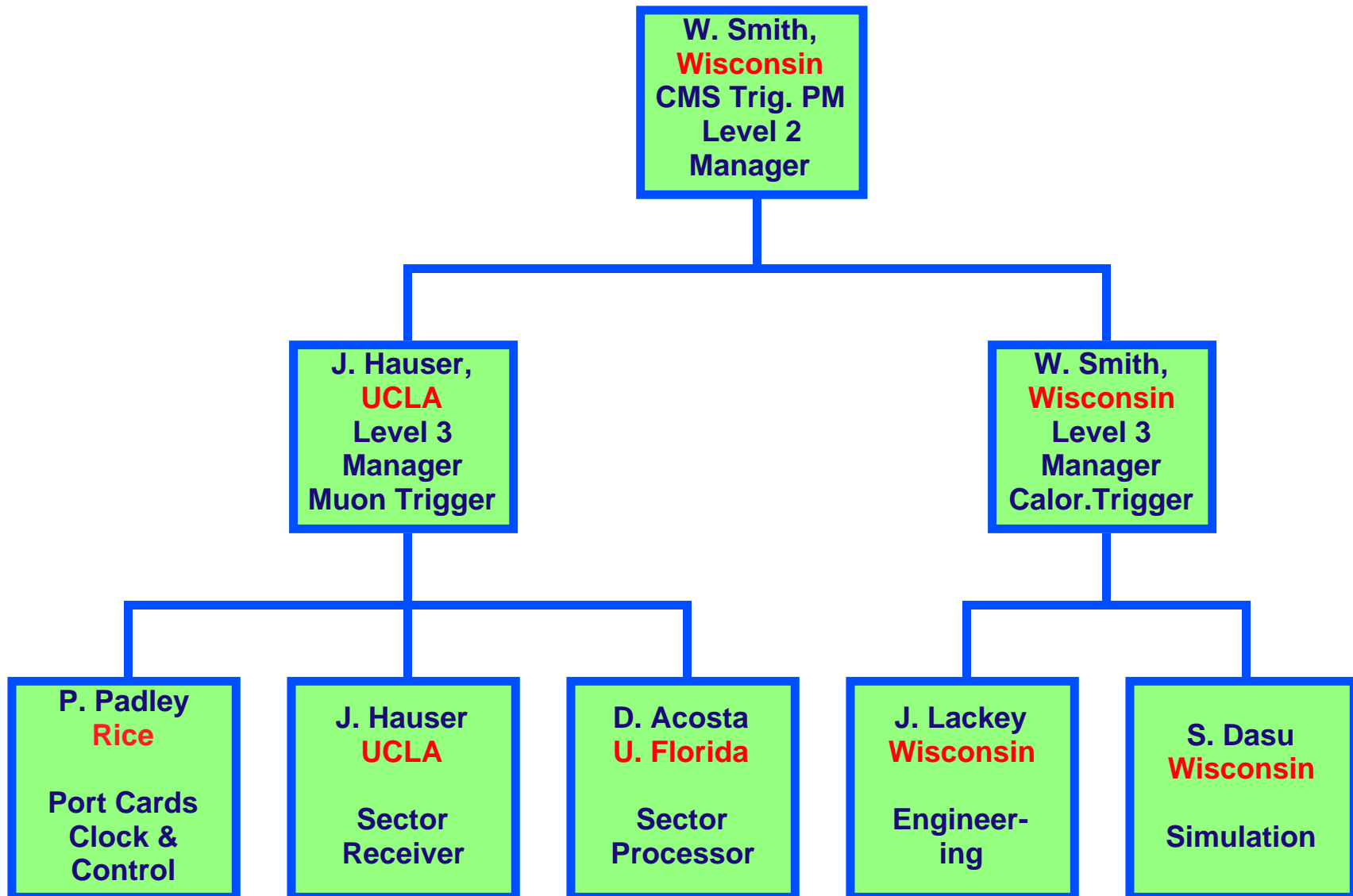
muon threshold = transverse momentum threshold

calorimeter threshold = transverse energy threshold

e/γ — electron/photon trigger, e_b — trigger on electron from b-quark decay



U. S. Trigger Organization





Trigger Project Management

CMS Annual Reviews

- **April: TriDAS Status**
 - Progress, draft R&D plans & expenses for next year
- **November: TriDAS Internal Review**
 - R&D Plans/Progress, Cost & Schedule, Milestones
 - Finalize R&D plans & expenses for next year
 - Internal CMS Review w/CMS referees
- **Internal Electronics Reviews by LHC Electronics Board CMS Reps.**
 - G. Hall (Imperial), G. Stefanini (CERN), W. Smith (Wisc.)
 - Reports to CMS Management Board (next trigger review in Fall '98)

US Reviews/Reporting

- **Monthly Video Conferences:**
 - Florida, Rice, UCLA, Wisconsin, Davis (sim)
 - Review Progress, milestones, simulation activities
- **Integration Meetings:**
 - Calorimeter Trigger: FNAL, Maryland, Wisconsin
 - Muon Trigger: Ohio, Florida, Rice, UCLA, Wisconsin, others.
- **Annual Site Visits:** Florida, Rice, UCLA



Calorimeter Trig. Costs at L4

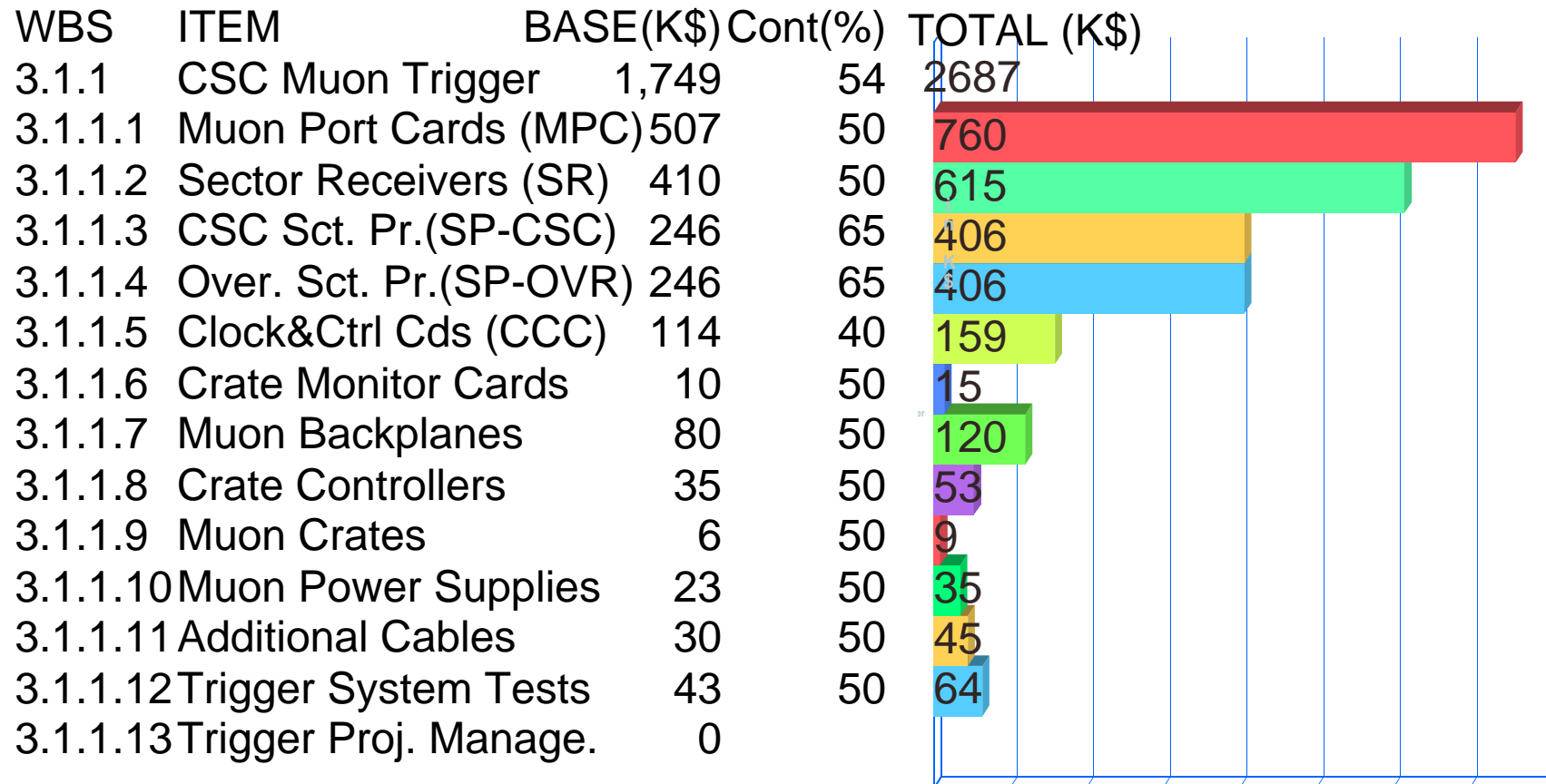
WBS	ITEM	BASE(K\$)	Cont(%)	TOTAL (K\$)
3.1.2	Cal.Regional Trigger	4,388	50	6581
3.1.2.1	Prototypes	441	46	643
3.1.2.2	Preproduction ASICs	553	47	811
3.1.2.3	Test Facilities	78	50	117
3.1.2.4	Power Supplies	82	30	106
3.1.2.5	Crates	35	30	45
3.1.2.6	Backplane	194	54	299
3.1.2.7	Clock & Control Card	132	40	185
3.1.2.8	Receiver Card	1,670	54	2571
3.1.2.9	Electron ID Card	744	50	1116
3.1.2.10	Jet Summary Card	170	50	254
3.1.2.11	Cables	7	30	9
3.1.2.12	DAQ Processor			
3.1.2.13	Crate Monitor Card			
3.1.2.14	Trigger Tests	282	50	423
3.1.2.15	Project Management			

Changes since last May 1997 Review:

- Contingency analysis performed at lowest level (increased from 39->50%)
- Bottoms-up recosting & new WBS (no substantial *net* cost change)
- Cost profile pushed back 6 months on average



Muon Trigger Costs at L4

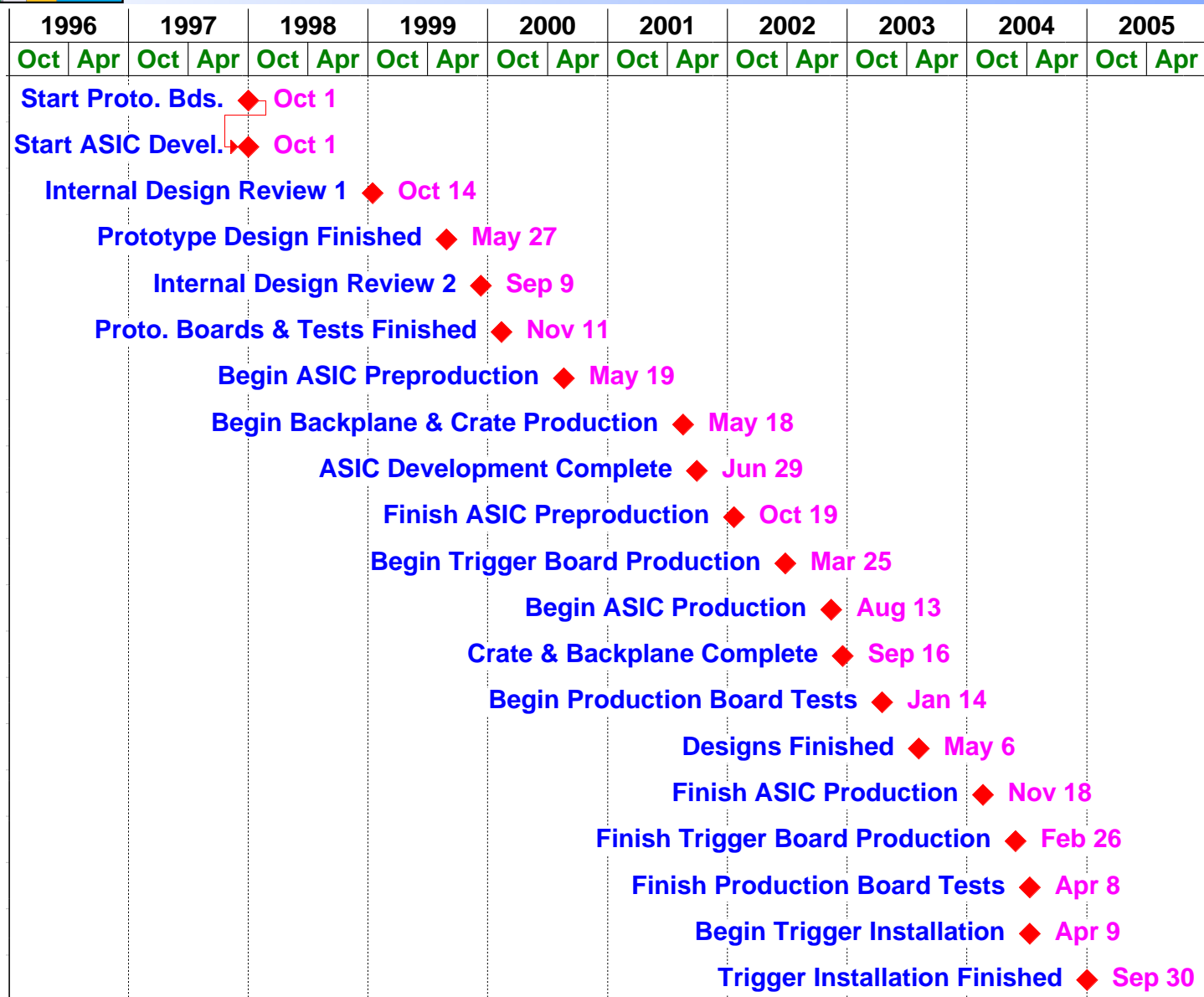


Changes since last May 1997 Review:

- Contingency analysis performed at lowest level (increased from 39->50%)
- New Architecture & removal of 4th station reduces cost (see next transp.)
- Bottoms-up recosting & new WBS (small cost reduction)
- Cost profile pushed back 6 months on average



Cal. Trig. Schedule & Milestones





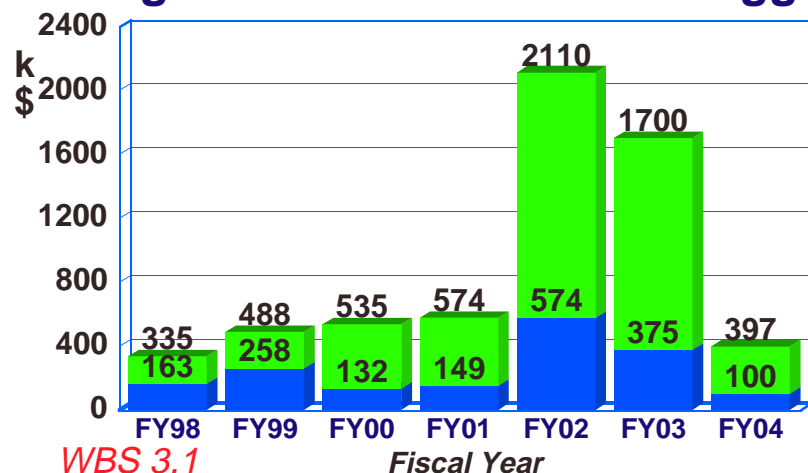
Muon Trig. Schedule & Milestones

1996		1997		1998		1999		2000		2001		2002		2003		2004		2005	
Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr	Oct	Apr
Finish Initial Design ♦ May 13																			
Begin Prototype Design ♦ Oct 1																			
		Finish Prototype Design ♦ May 13																	
Begin Prototype Construction ♦ Apr 2																			
		Finish Prototype Construction ♦ Sep 30																	
		Begin Prototype Test ♦ Aug 20																	
				Finish Prototype Test ♦ Jul 21															
				Begin Final Design ♦ Jun 12															
						Finish Final Design ♦ Jul 22													
						Begin Production ♦ Jan 22													
								Finish Production ♦ Nov 25											
										Begin Installation ♦ Aug 20									
												Finish Installation ♦ Apr 29							
										Begin Trigger System Tests ♦ Apr 30									
												Finish Trigger System Tests ♦ Sep 9							



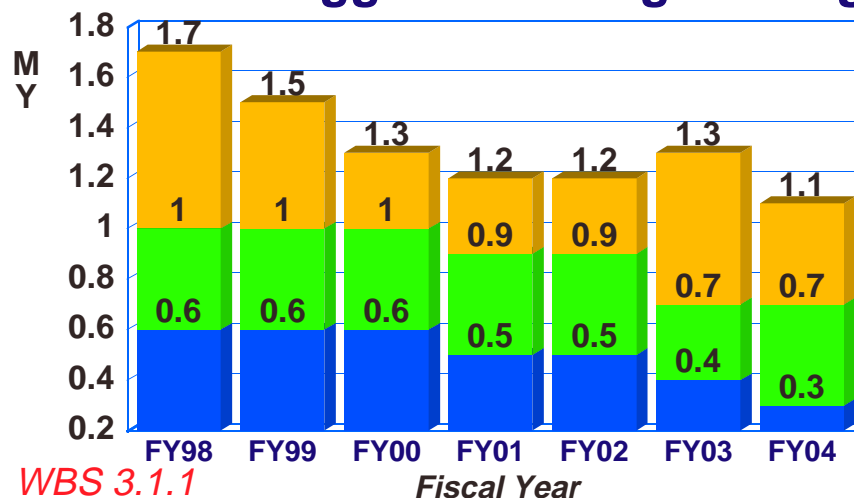
Obligations & Resources

Obligations for Muon & Cal Triggers



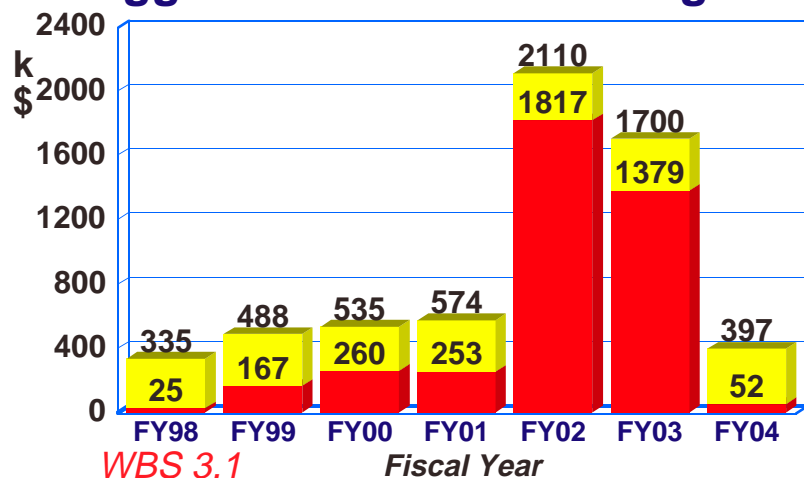
■ Muon Trig. ■ Cal. Trig.

Muon Trigger Peak Engineering



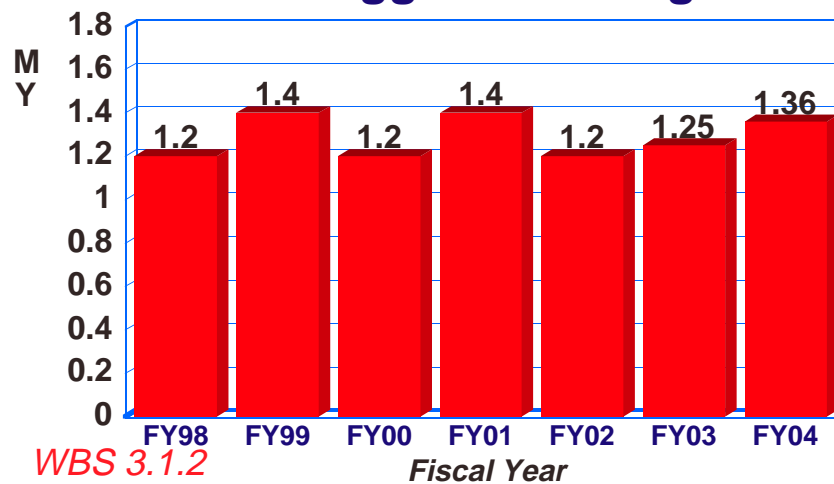
■ UCLA ■ Florida ■ Rice

Trigger M&S and EDIA Obligations



■ M&S ■ EDIA

Calorimeter Trigger Peak Engineering



■ Wisconsin



- Designed for 160 MHz
- Being built



- **Prototype constructed**
- **Prototype Clock & Control Card built**
- **Signal performance excellent @ 160 MHz**
- **Confirmation of design feasibility**



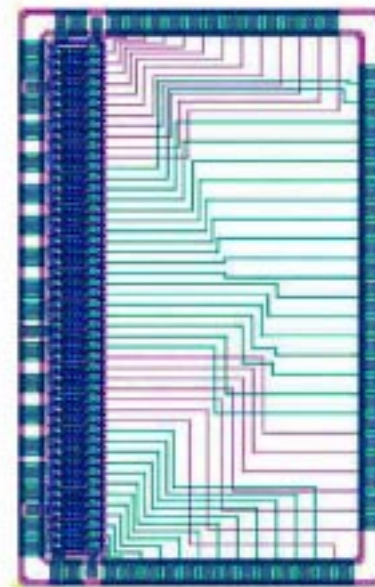


Muon Trigger Status

**Operation in
Summer '98
test beam**

16-ch Comparator ASICs ready

- Excellent performance (1mV offsets)
- Comparator board routed, sent to be manufactured



First Cathode LCT card built

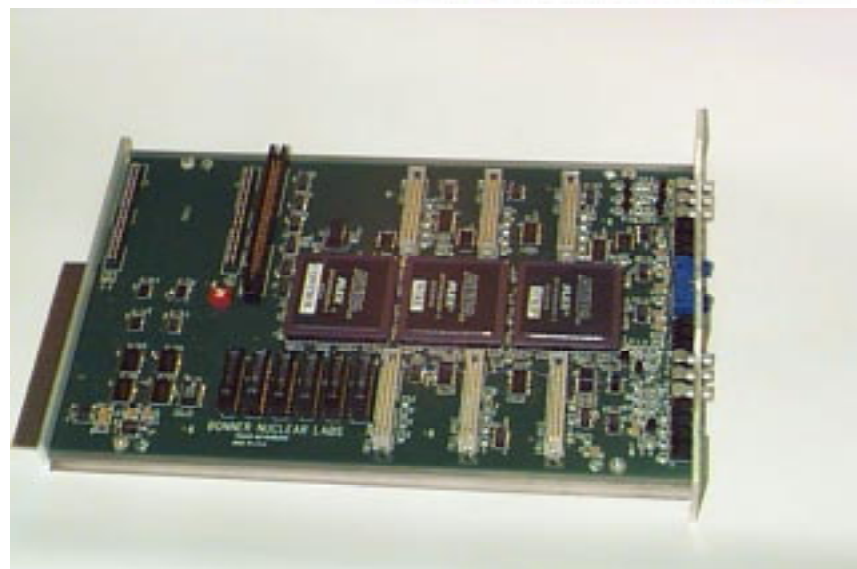
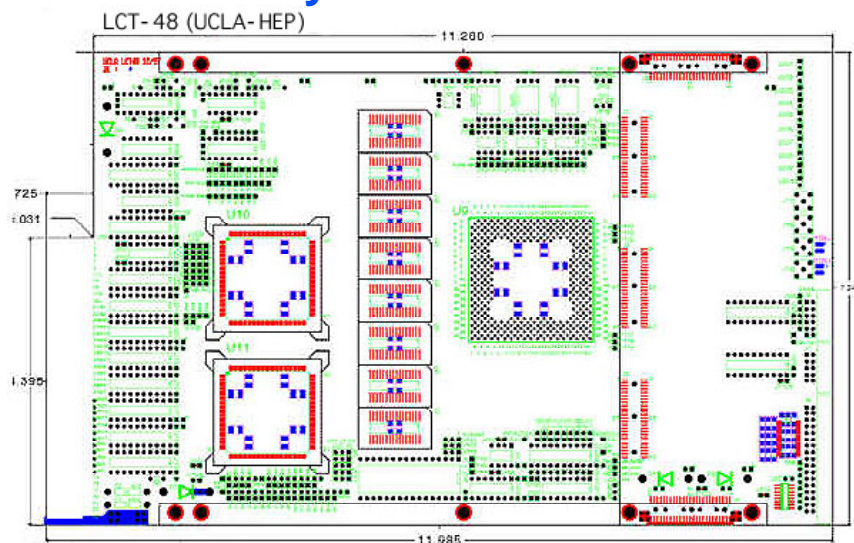
- Software being debugged

First Anode LCT card built

- Assembly & software next

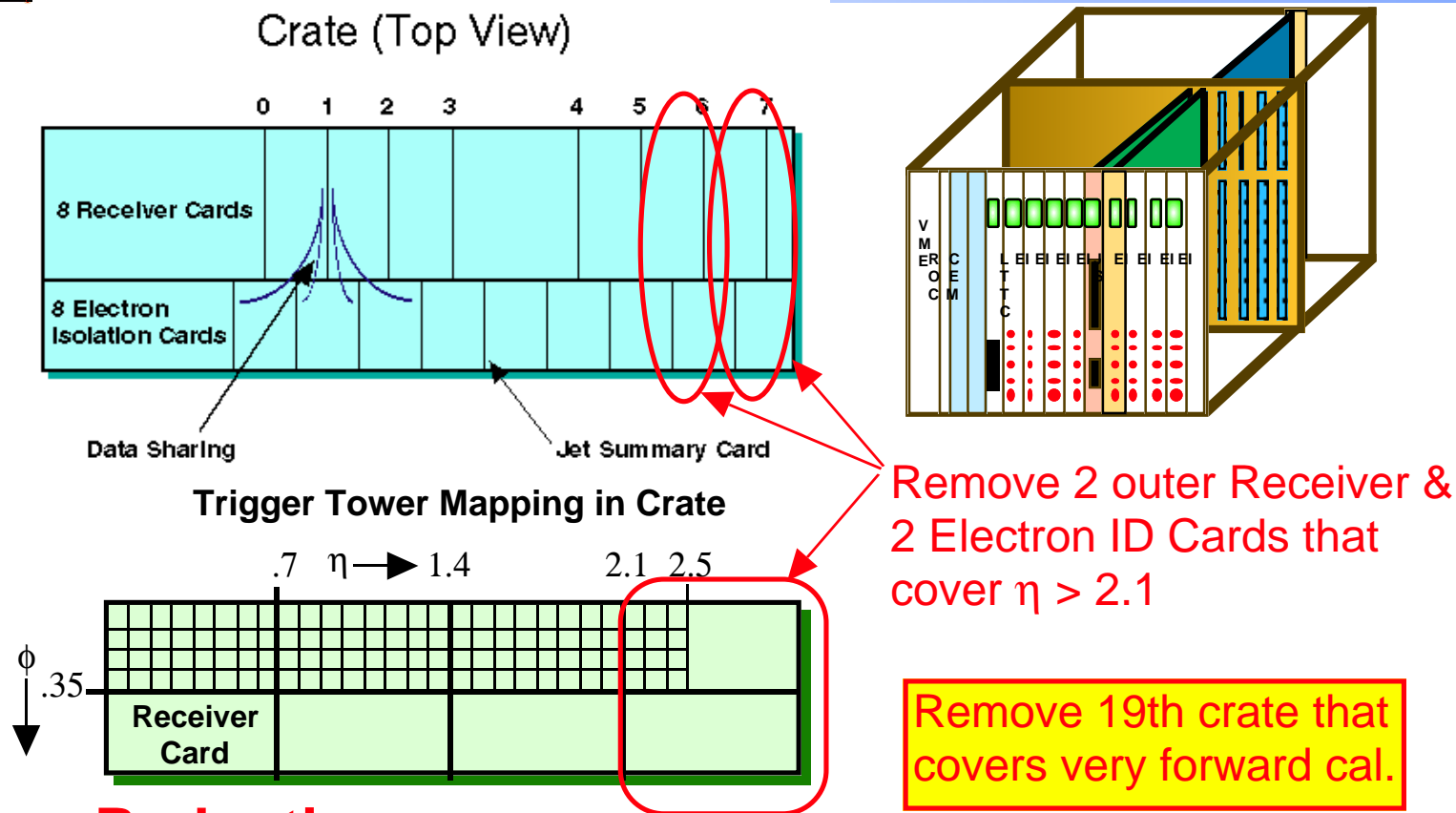
First Trigger Motherboard built

- Ready for test w/LCT card





Option: Rescope Cal. Trig.



Reductions:

- Receiver & Electron ID Cards: 176 to 132
- Jet Summary Cards & Crates: 22 to 21
- Base Cost reduced by 590K

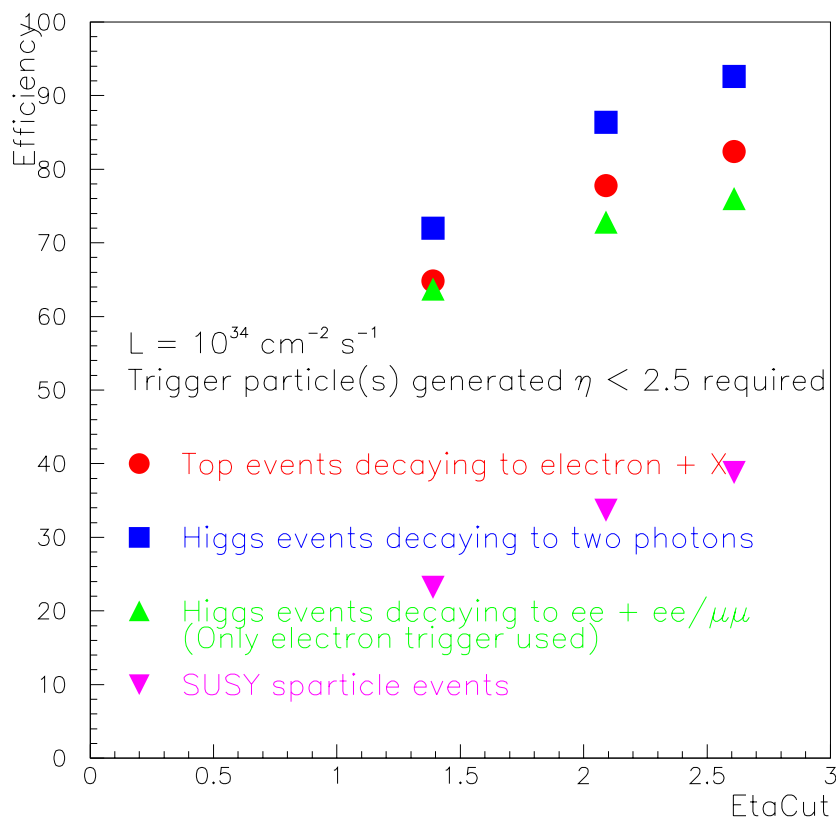
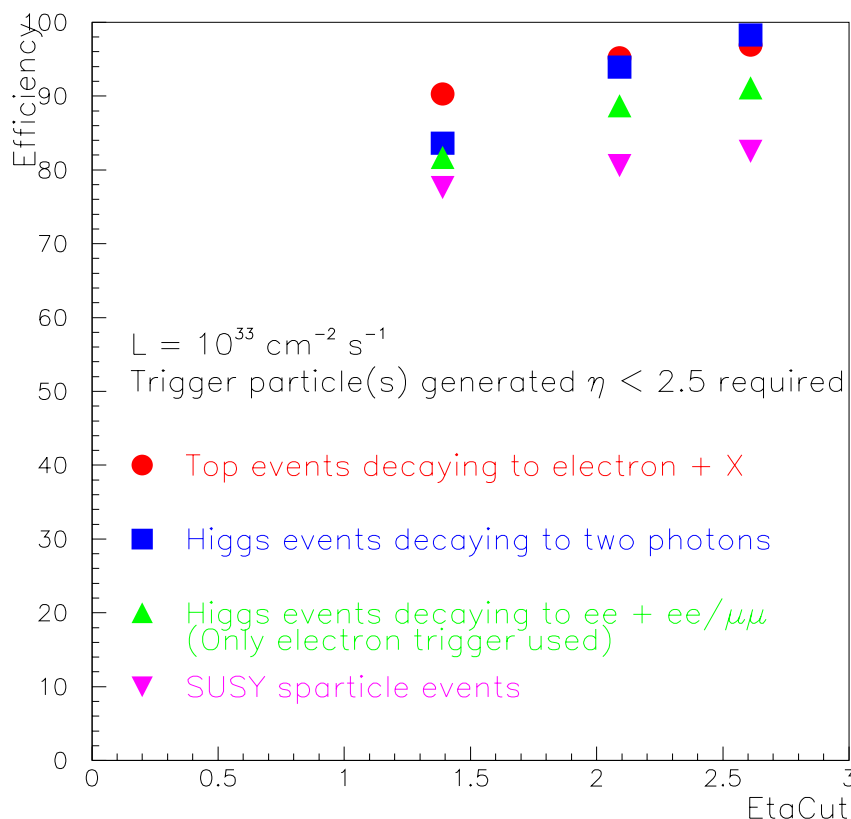


Impact of Cal. Trig. Rescope

Low Luminosity:

High Luminosity:

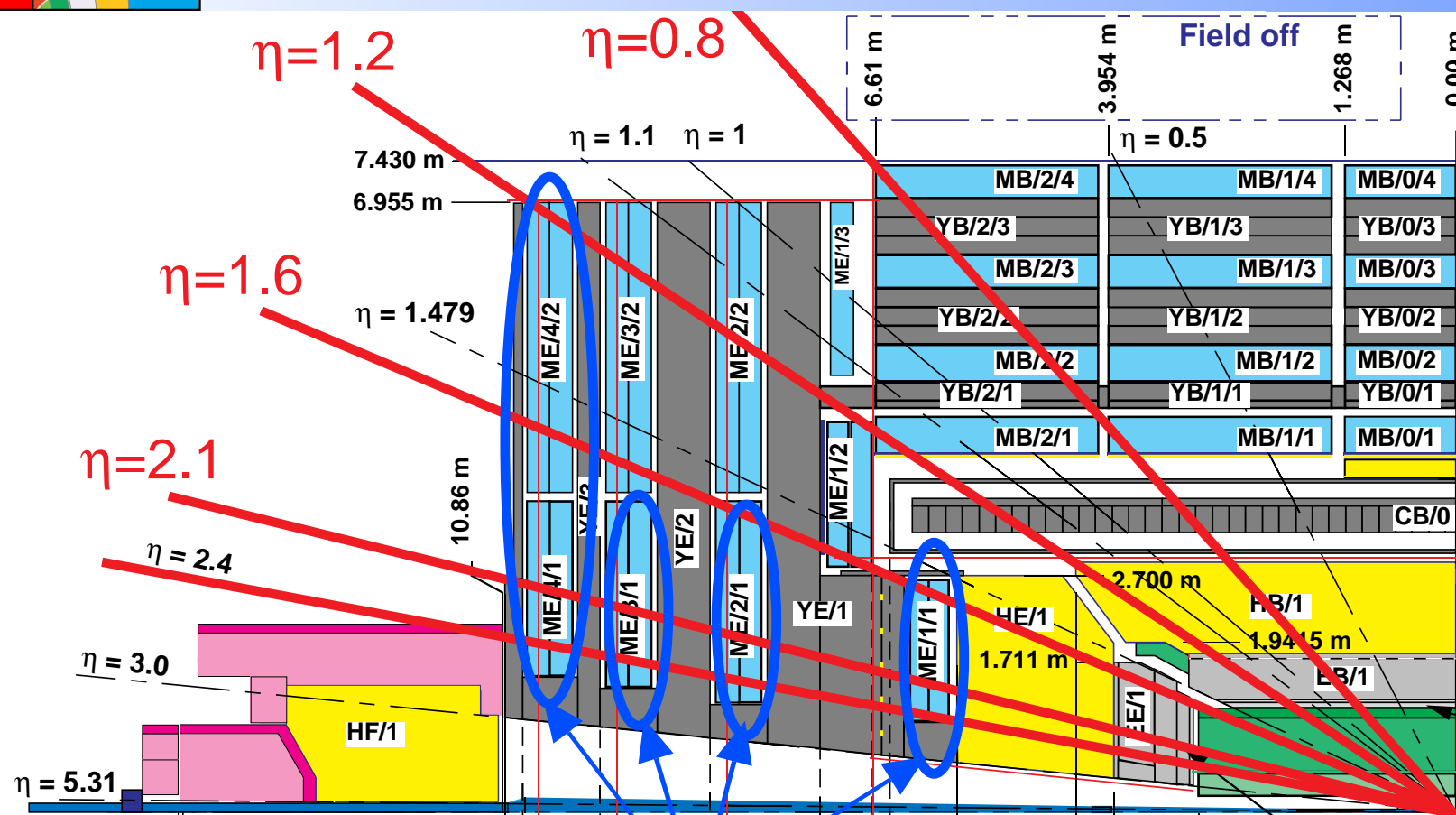
Efficiency versus eta cut for trigger descope



CMS Decision: Do not rescope Cal. Trig.



Option: Rescope CSC Trigger



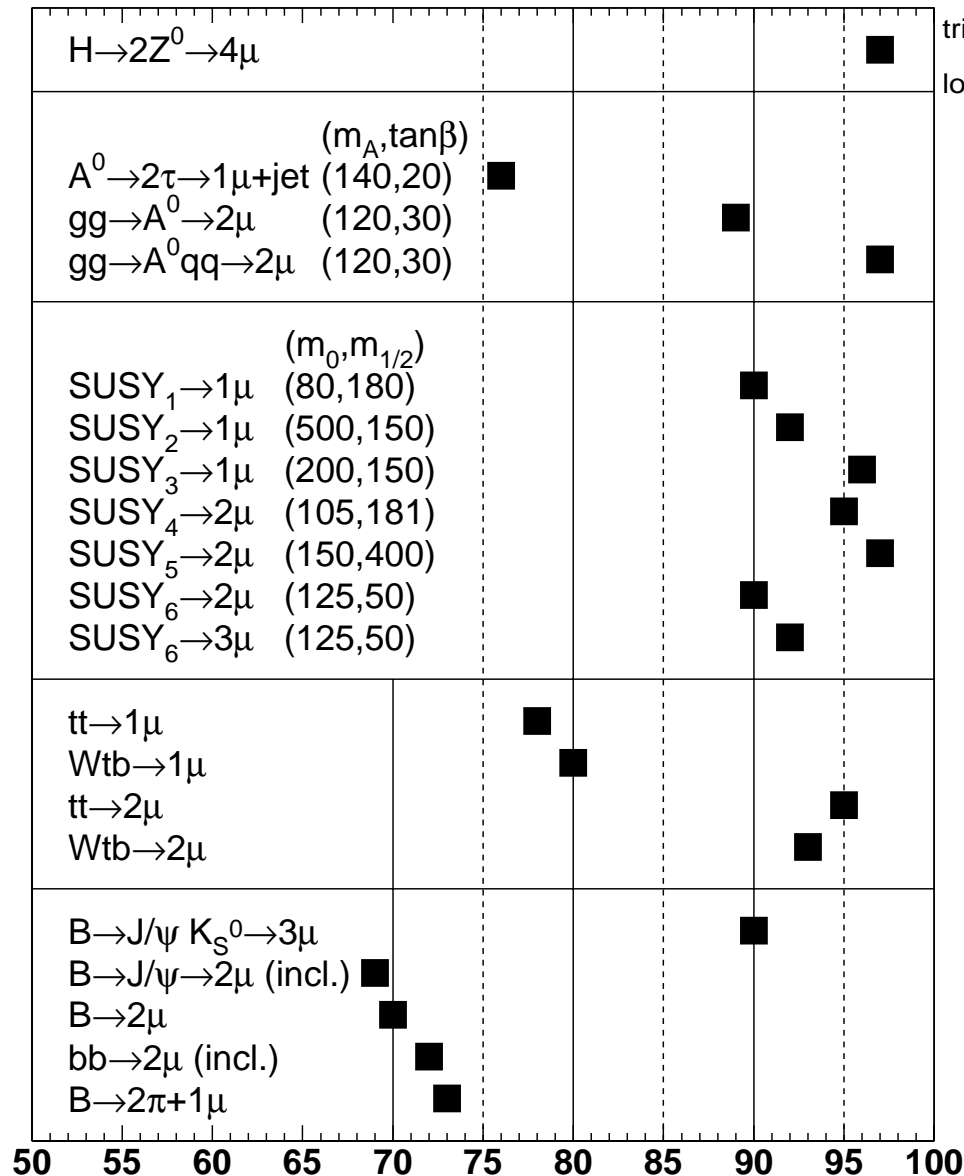
Remove:

- ME*/1 & ME4 processing (cut trigger at $\eta > 1.6$)
- 5 of 7 Fibers/Port Card (only 1 stub per 60°)

Base Cost reduced by 404K (incl. new design)



Impact of CSC trig. rescope



trigger acceptance for $|\eta| < 1.6$ / acceptance for $|\eta| < 2.4$ (%)

low lumi. trigger thresholds - $p_t^{1\mu} = 7$ GeV, $p_t^{2\mu} = 4$ GeV

Ratio of descope CSC to previous baseline muon trigger efficiency for low luminosity running.

CMS Decision: Do not descope in η but approve other changes:

- **Fourth Station Removed**
 - small loss in efficiency
- **New Architecture**
 - 60° port cards (fewer)
 - keep links/port card
- **New SR/SP design**
 - fewer SR's, SP's
 - fewer Crates

New Base Cost:

- **Reduction by 230K**



Committee Concerns & Corrective Actions

From May 97 Lehman Review:

- "Base the assignment of contingency and risk on the maturity of the design, and specify it item by item, rather than globally for each subsystem."
 - This has been done at the lowest level of the WBS and is available in the new MS Project files.
- "Re-evaluate the Level 1 trigger latency in the context of the details of the evolving system design."
 - This was done in a detailed TRIDAS review in November 1997 and is scheduled for reevaluation during an additional review planned for Nov. 1998.

These concerns have been addressed



Conclusions - Trigger

- **Trigger algorithms satisfy physics requirements**
 - Active simulation program producing results
- **Hardware design to implement algorithms**
 - Full conceptual design with considerable engineering
 - Extensive prototyping & test program
 - "Proof of principle" of critical items
 - Number of successes already
- **New Costing**
 - 4th muon station removed & Architecture revision
 - Contingency increased from 30% to 50%
 - Calculated at the lowest WBS level according to US CMS method
- **Fully resource loaded schedule**
 - Carefully matched to project & base support
 - Experienced team in place